

LU-HF AGE OF MARTIAN METEORITE LARKMAN NUNATEK 06319. J.T. Shafer¹, A.D. Brandon², T.J. Lapen³, M. Righter³, B. Beard^{4,6}, and A.H. Peslier^{5,2}, ¹Lunar and Planetary Institute, Houston, TX 77058 (shafer@lpi.usra.edu), ²NASA-JSC, Houston, TX 77058, ³Department of Geosciences, University of Houston, Houston, TX 77204, ⁴Department of Geology and Geophysics, University of Wisconsin, Madison, WI 53204, ⁵Jacobs Technology, E.S.C.G., Mail Code JE23, 2224 Bay Area Blvd, Houston, TX 77058, USA, ⁶NASA Astrobiology Institute.

Introduction: Lu-Hf isotopic data were collected on mineral separates and bulk rock powders of LAR 06319, yielding an age of 197 ± 29 Ma. Sm-Nd isotopic data and *in-situ* LA-ICP-MS data from a thin section of LAR 06319 are currently being collected and will be presented at the 2009 LPSC. These new data for LAR 06319 extend the existing data set for the enriched shergottite group.

Martian meteorites represent the only opportunity for ground truth investigation of the geochemistry of Mars [1]. At present, approximately 80 meteorites have been classified as Martian based on young ages and distinctive isotopic signatures [2]. LAR 06319 is a newly discovered (as part of the 2006 ANSMET field season) martian meteorite that represents an important opportunity to further our understanding of the geochemical and petrological constraints on the origin of Martian magmas. Martian meteorites are traditionally categorized into the shergottite, nakhlite, and chassignite groups. The shergottites are further classified into three distinct isotopic groups designated depleted, intermediate, and enriched [3,4] based on the isotope systematics and compositions of their source(s). The depleted shergottite group (including QUE 94201, Y-980459, DaG 476, SaU 005/008, Dhofar 019, and NWA 1195) were derived from incompatible element depleted sources and are characterized by superchondritic initial $^{143}\text{Nd}/^{144}\text{Nd}$ ($\epsilon^{143}\text{Nd}_i = 36\text{--}39$ [4]) and $^{176}\text{Hf}/^{177}\text{Hf}$ ($\epsilon^{176}\text{Hf}_i = 46\text{--}50$ [4]) at the time of their crystallization [3,4] while the enriched shergottites (including Shergotty, Zagami, NWA 856, RBT 04262, NWA 4468, and Los Angeles) are identified by complementary subchondritic $\epsilon^{143}\text{Nd}_i$ and $\epsilon^{176}\text{Hf}_i$ (-7 to -6.5 and -18 to -13.2 , respectively) [4]. The depleted shergottite mantle source(s) did not form synchronously with the enriched shergottite mantle source. This is evidenced by coupled ^{142}Nd - ^{143}Nd systematics [5], suggesting that the depleted and enriched sources may have formed during the cooling of a global magma ocean where the depleted source represents a mixture of early formed cumulates and residual melts [4] and the enriched source being residual late-stage melt analogous to lunar KREEP [4,5]. The intermediate and enriched shergottites have been modeled as variable mixtures of depleted Martian mantle and the residual late-stage trapped melt [6,7].

LAR 06319 Description: LAR 06319 is an olivine-phyric shergottite consisting of olivine phenocrysts (up to 3 mm diameter) set in a matrix of pyroxene and maskelynite interspersed with minor oxide phases, phosphate phases, and shock melt veins. Maskelynite is typically present as elongate laths and interstitial glass between other phases, making it difficult to isolate optically pure maskelynite during mineral separation. Olivine is typically brown, most likely due to shock effects, and often contains inclusions of oxide phases, pyroxene, and maskelynite in their cores. The cores of the large olivines are typically more magnesian than the rims (Fo_{73} vs Fo_{60}), while smaller olivines are not zoned and more Fe rich (Fo_{50}). Pyroxene is common in LAR 06319, consisting primarily of pigeonite that is variably zoned as well as augite and Fe-rich pigeonite. Limited dismantling of the first-crystallized big olivines and pyroxenes indicates mechanical disruption of these phenocrysts becoming xenocrysts in their own evolving magma during ascent. Olivine and augite appear optically similar in color, making definitive identification during hand-picking difficult. In addition, the small maskelynite grain size and typical intergrowths of maskelynite and pyroxene made preparation of optically pure phases for isotopic analysis difficult to gather in significant abundance.

Analytical: An ~800 mg aliquot of LAR 06319 was crushed in an alumina mortar and pestle that was precleaned by twice grinding Ottawa quartz sand in ethanol. The crushed material was sieved into various size fractions, of which the 100-200 mesh fraction was used for mineral separations via magnetic separation, heavy liquids, and hand-picking. Five mineral fractions were isolated from the 100-200 mesh cut: maskelynite, maskelynite-rich hybrids (h-mask, hybrid crystals composed primarily of maskelynite and minor pyroxene, olivine, oxide, and phosphate phases), pyroxene, pyroxene-rich hybrids (h-pyx, analogous to h-mask), and olivine. The pyroxene, h-mask, and three bulk rock (BR-1, BR-2, and BR-3) samples from the finest sieved fraction were analyzed for $^{176}\text{Hf}/^{177}\text{Hf}$ and $^{176}\text{Lu}/^{177}\text{Hf}$ ratios. Analysis of the other fractions for Lu-Hf and Sm-Nd are currently underway. BR-1, pyroxene, and h-mask fractions were lightly leached with cold acetic acid in an ultrasonicator for 10 min, while BR-2 and BR-3 were leached with cold 0.1N HCl and

2N HCl, respectively. All leachates were saved and will be analyzed in the future. Neodymium, Sm, Lu, and Hf were purified using a 4 column procedure beginning with Fe removal via an anion exchange (AG1X8-200 resin) and HCl, then isolation of Hf (Ln-spec resin), followed by isolation of the REE via cation exchange (AG50W-X8-200 resin), and concluding with isolation of Lu, Sm, and Nd (AG50W-X4 resin in NH_4 form with α -HIBA). Lutetium and Hf were analyzed using a GV Instruments *IsoProbe* MC-ICP-MS at the University of Wisconsin-Madison.

Grain mounts made from the olivine, pyroxene, and hybrid-maskelynite mineral separates were analyzed via LA-ICP-MS at the University of Houston. A glass wafer of USGS standard reference material BHVO-2G was used for calibration.

Results: The Lu-Hf age of LAR 06319 is 197 ± 29 Ma (2σ , MSWD=1.18) based on a 5 point internal isochron (Fig. 1). The derived initial $^{176}\text{Hf}/^{177}\text{Hf}$ isotope ratio is 0.282141 ± 0.00001 (2σ). The initial $\epsilon^{176}\text{Hf}$ of LAR 06319 is -18.0, identical to that of Zagami (-18.0 to -16.5) [9,4], and similar to Shergotty (-17.3 to -16.4) [8,4] and RBT 04262 (-17.6) [6] and slightly more enriched than Los Angeles (-15.3 to -13.2) [8,4].

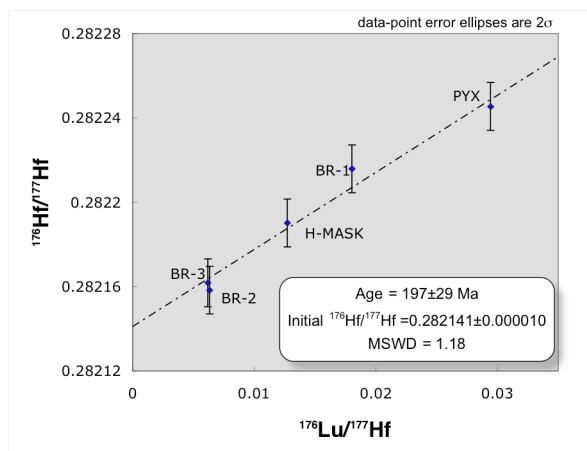


Figure 1. Lu-Hf isochron diagram for LAR 06319. Model-1 of the program IsoPlot (v.3.50) was used to calculate the isochron.

The separation of BR-1 from BR-2 and BR-3 can likely be accounted for by the difference in pre-dissolution leaching. BR-1 was only lightly leached in cold acetic acid while BR-2 and BR-3 were more aggressively leached in HCl. Previous work has shown that Lu and Hf are sensitive to the leaching procedure in fine-grained SNC samples and that they can be decoupled even during a gentle leach [7]. Leaching of LAR 06319 resulted in correlated changes in Lu/Hf

and $^{176}\text{Hf}/^{177}\text{Hf}$ ratios. A plot of $^{176}\text{Hf}/^{177}\text{Hf}$ vs $1/\text{Hf}$ for the leached bulk rock results in a straight line indicating that the HCl appears to have removed a radiogenic Hf phase(s).

Average analyses of olivine, pyroxene (predominantly pigeonite), and maskelynite are shown in Fig. 2.

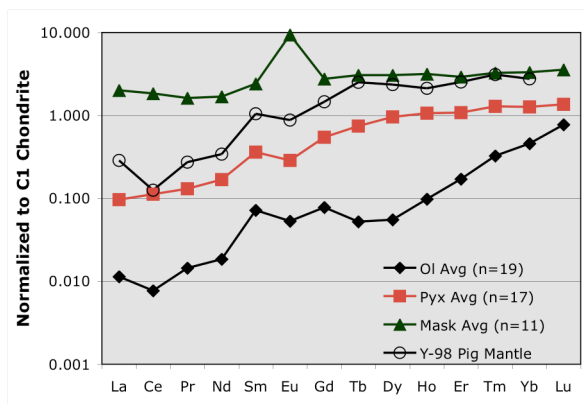


Figure 2. REE profiles of average mineral compositions determined from prepared grain mounts of LAR 06319 mineral separates. Ol = olivine, Pyx = pyroxene, and Mask = maskelynite.

Pyroxenes and olivines have LREE depleted profiles while maskelynite shows the typically flat profile of plagioclase with characteristic positive Eu anomaly. REE contents of the pyroxenes are similar to slightly lower than the rims of pigeonite from Y-980459, which is considered to represent a primary shergottitic melt [10].

Summary: LAR 06319 is clearly a member of the enriched shergottite group and has nearly identical Lu-Hf systematics to Shergotty, Zagami, and RBT 04262. The 197 Ma age is intermediate between that of the young enriched shergottites (Shergotty (188 Ma), Zagami (155 Ma), and Los Angeles (159 Ma)) and the oldest enriched shergottite RBT 04262 (225 Ma) indicating continual magmatism for at least 70 Ma [8,9,6].

References: [1] McSween H.Y. (1994) *Meteoritics*, 29, 757-779. [2] Met. Society, Meteoritical Bulletin Database (<http://tin.er.usgs.gov/meteor/metbull.php>). [3] Symes, S.J.K. et al. (2008) *GCA*, 72, 1696-1710. [4] DeBaille, V. et al. (2008) *EPSL*, 269, 186-199. [5] DeBaille, V. et al. (2007) *Nature*, 450, 525-528. [6] Lapen T.J. et al. (2008) *LPS XXXIX*, Abstract #2073. [7] Borg L.E. and Draper D.S. (2003) *Meteoritics & Planet. Sci.*, 38, 1713-1731. [8] Bouvier A. et al. (2008) *EPSL*, 266, 105-124. [9] Bouvier A. et al. (2005) *EPSL*, 240, 221-233. [10] Usui T. et al. (2008) *GCA*, 72, 1711-1730.